Community Modeling Environment at the
Southern California Earthquake Center

Principles, Architecture and Lessons Learned

Jean-Bernard Minster
UCSD/SIO -- SCEC

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SC/EC

an NSF + USGS center

NSF National Science Foundation

USGS science for a changing world

TeraGrid

NCSA

PITTSBURGH SUPERCOMPUTING CENTER

ARGONNE NATIONAL LABORATORY · UNIVERSITY OF CHICAGO

USCGRID

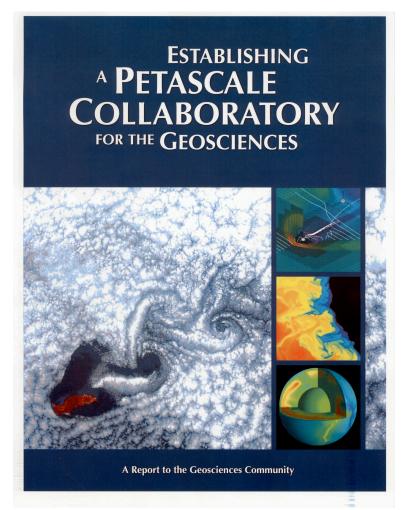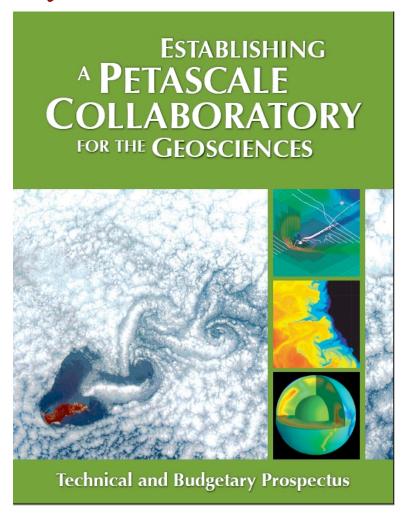**ISI** Information Sciences Institute

the IRIS CONSORTIUM

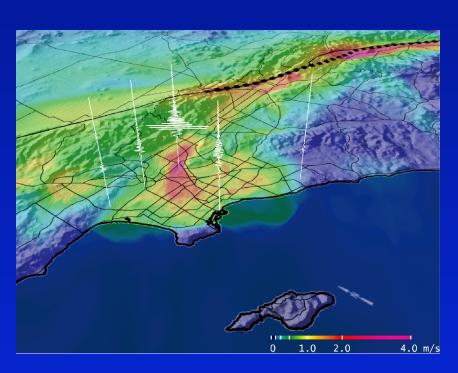# The Geoscientific Community Is Pursuing a Petascale Collaboratory

SCEC: An NSF + USGS Research Center

Overview of Talk

1. Earthquake System Science and SCEC CME

2. SCEC's Earthquake System Science research: Pathways, and Platforms

3. Selected aspects that might be adapted to Icesheet Community modeling

SCEC Earthquake System Science – Spanning microseconds to millennia and from microns to 1,000 km

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Community Modeling Environment

- SCEC's *collaboratory* for earthquake system science

- provides the cyberinfrastructure for executing the *computational pathways* of physics-based seismic hazard analysis (SHA)

- developed and operated by the *CME Collaboration*

- main facilities are the *PetaSHA computational platforms*

- Participation by SCEC community is coordinated through a *Planning Committee*

Geosystems: Defined by Predicted Behavior

- A geosystem comprises a set of interacting elements that changes in time according to a set of prescribed laws, designed to model *specific behaviors* observed in the Earth environment
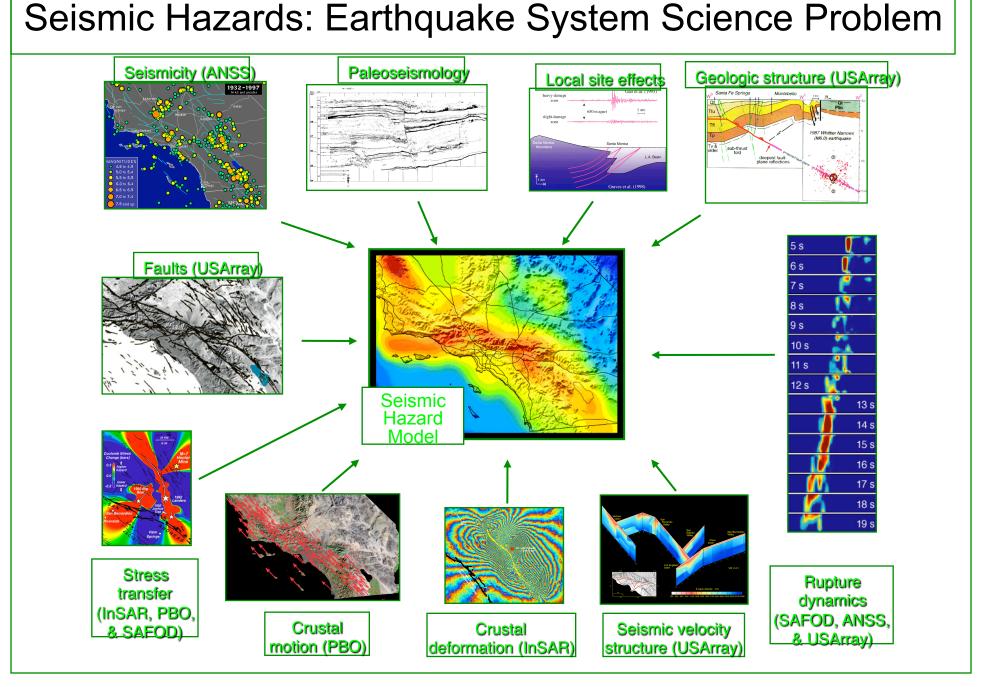
- In other words, *the behavior defines the system*

Geosystem	Behavior
Climate system (a.k.a. "Earth system")	climate
mantle convection	plate tectonics
core dynamo	magnetic field
southern polar vortex	ozone hole
orogen	mountain building and erosion
active fault system	earthquakes
super-cell thunderstorm	tornado
volcano	magmatic eruption
petroleum reservoir	accumulation & flow of petroleum
ENSO	El Niño
ICE Sheet	Disintegration? Sea Level change?

Seismic Hazards: Earthquake System Science Problem

Seismicity (ANSS)

Paleoseismology

Local site effects

Geologic structure (USArray)

Faults (USArray)

Seismic Hazard Model

Stress transfer (InSAR, PBO, & SAFOD)

Crustal motion (PBO)

Crustal deformation (InSAR)

Seismic velocity structure (USArray)

Rupture dynamics (SAFOD, ANSS, & USArray)

SCEC Collaboratory

KNOWLEDGE REPRESENTATION & REASONING
Knowledge Server
Knowledge base access, Inference
Translation Services
Syntactic & semantic translation

Knowledge Base

Ontologies
Curated taxonomies,
Relations & constraints

Pathway Models
Pathway templates,
Models of simulation codes

DIGITAL LIBRARIES

Navigation & Queries
Versioning,
Topic maps

Mediated Collections
Federated access

Data Collections

Data & Simulation Products

FSM
RDM
AWM
SRM

Code Repositories

KNOWLEDGE ACQUISITION

Acquisition Interfaces
Dialog planning,
Pathway construction strategies

Pathway Assembly
Template instantiation,
Resource selection,
Constraint checking

Users

GRID
Pathway Execution
Policy, Data ingest, Repository access
Grid Services
Compute & storage management, Security
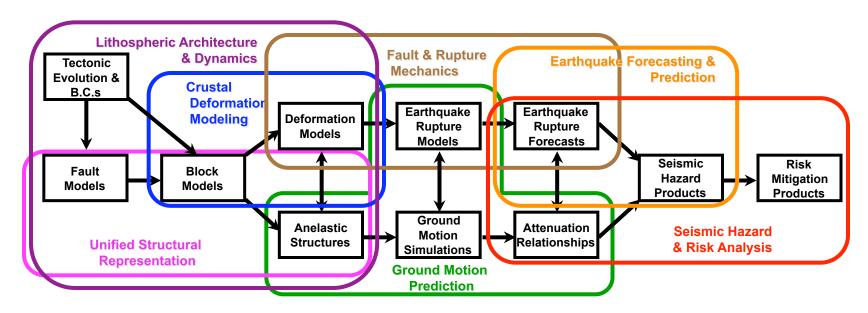
Pathway Instantiations

Computing

Storage

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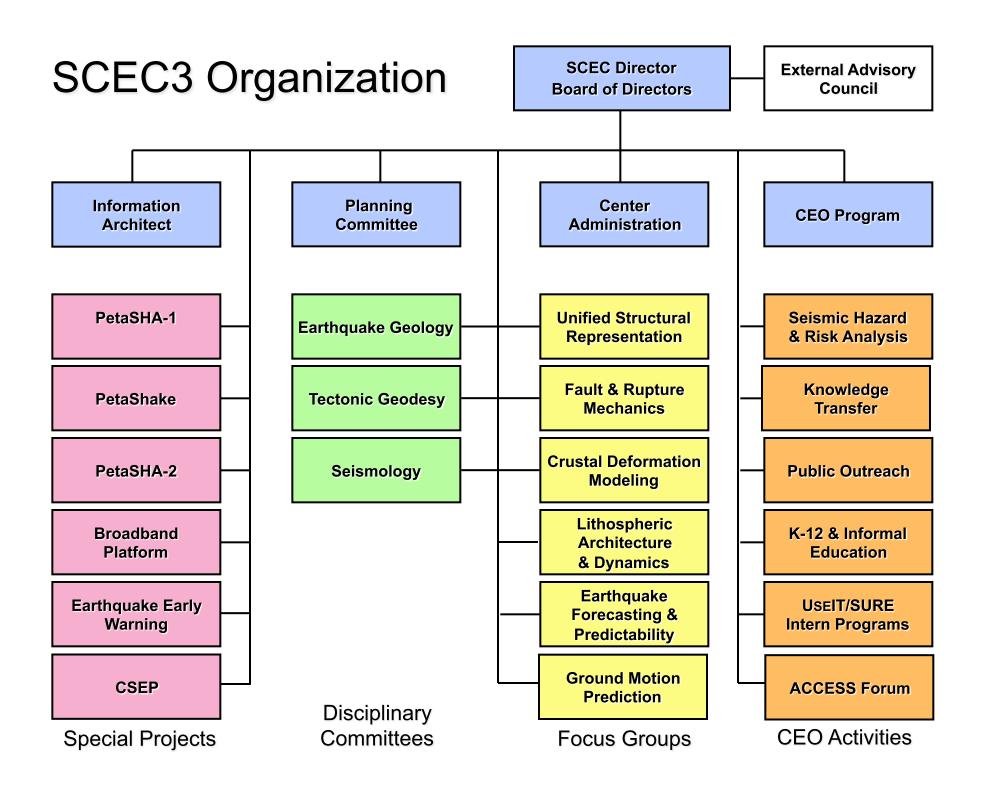LANL, 18-20 August 2008

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Southern California Earthquake Center

- **Involves 500+ scientists at 55 institutions worldwide**

- **Focuses on earthquake system science using Southern California as a natural laboratory**

- **Translates basic research into practical products for earthquake risk reduction**

SCEC Master Model & Focus Groups

SCEC3 Organization

SCEC Director Board of Directors	External Advisory Council

Information Architect	Planning Committee	Center Administration	CEO Program

PetaSHA-1	Earthquake Geology	Unified Structural Representation	Seismic Hazard & Risk Analysis
PetaShake	Tectonic Geodesy	Fault & Rupture Mechanics	Knowledge Transfer
PetaSHA-2	Seismology	Crustal Deformation Modeling	Public Outreach
Broadband Platform		Lithospheric Architecture & Dynamics	K-12 & Informal Education
Earthquake Early Warning		Earthquake Forecasting & Predictability	UseIT/SURE Intern Programs
CSEP		Ground Motion Prediction	ACCESS Forum

Special Projects	Disciplinary Committees	Focus Groups	CEO Activities

SHA Computational Pathways

1. Standard seismic hazard analysis
2. Ground motion simulation
3. Dynamic rupture modeling
4. Ground-motion inverse problem

Other Data
Geology
Geodesy

Unified Structural Representation — F3DT — 4 — *Improvement of models*

DFR — AWP — KFR — AWP — NSR — Ground Motions — *Physics-based simulations*

3

2

Earthquake Rupture Forecast — Attenuation Relationship — Intensity Measures — *Empirical models*

1

KFR = Kinematic Fault Rupture
DFR = Dynamic Fault Rupture
AWP = Anelastic Wave Propagation

NSR = Nonlinear Site Response
F3DT = Full 3D Tomography

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Types of SCEC Predictive Simulations In Time Scale Order (shortest time scale to longest time scale)
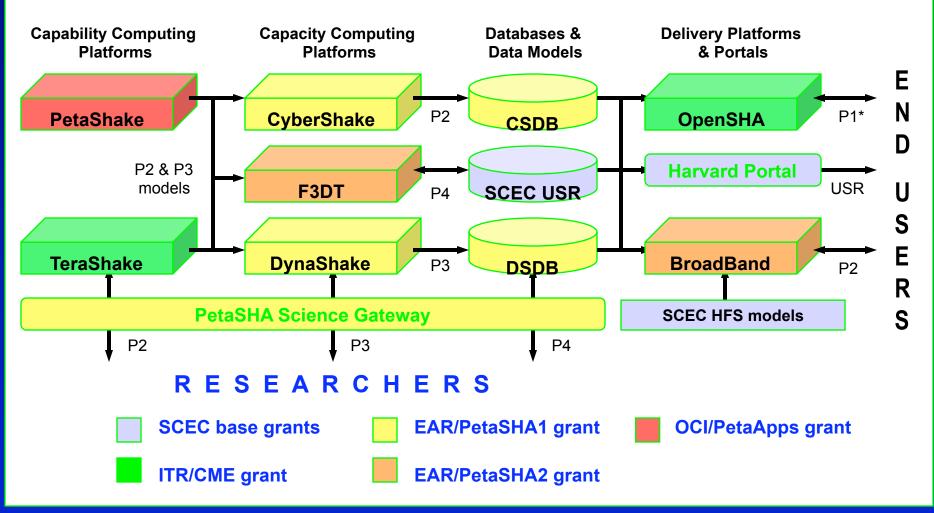
1. Dynamic Rupture Simulations
2. Large Wave Propagation Simulations
3. Earthquake Early Warning
4. Ensemble Probabilistic Simulations
5. Earthquake Predictions

Common Computing requirements:

- High performance/high throughput computing
- Verification/Validation
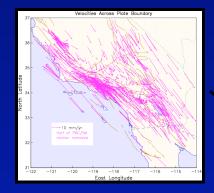- Visualization
- Data Management
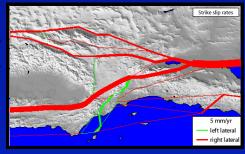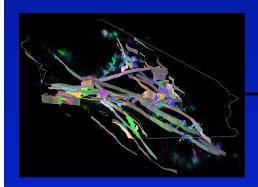- Scientific Workflows

PetaSHA Computational Platforms

Capability Computing Platforms

Capacity Computing Platforms

Databases & Data Models

Delivery Platforms & Portals

PetaShake

CyberShake → P2 → CSDB → OpenSHA → P1*

P2 & P3 models

F3DT → P4 → SCEC USR ↔ Harvard Portal → USR

TeraShake

DynaShake → P3 → DSDB → BroadBand → P2

PetaSHA Science Gateway

SCEC HFS models

P2   P3   P4

E N D   U S E R S

R E S E A R C H E R S

- SCEC base grants
- EAR/PetaSHA1 grant
- OCI/PetaApps grant
- ITR/CME grant
- EAR/PetaSHA2 grant

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Unified Structural Representation

Crustal Motion Map
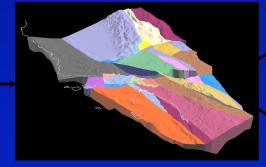
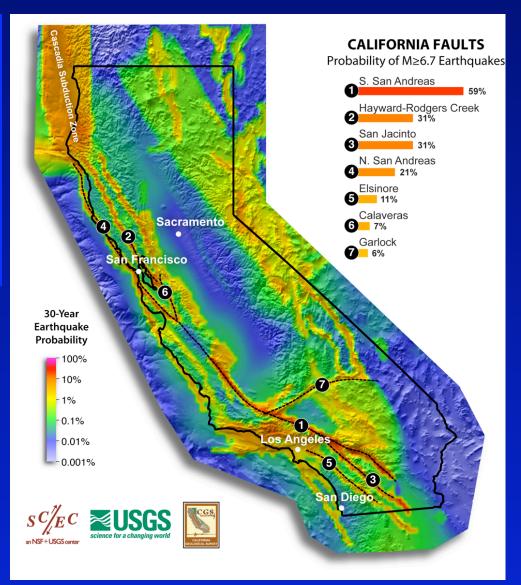Tectonic models
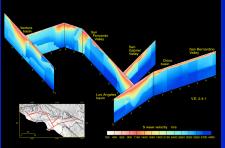
Community Fault Model

Community Block Model

Structural models

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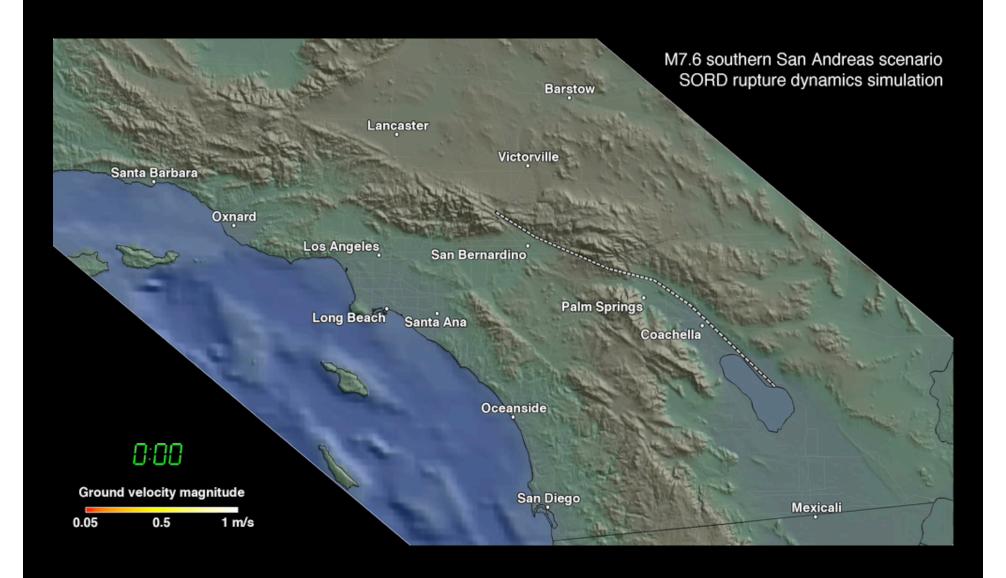LANL, 18-20 August 2008

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SORD: Support Operator Rupture Dynamics

- Non-planar spontaneous shear crack propagation within a 3D viscoelastic medium.

- Generalized finite difference method of "Support Operators."

- Logically rectangular hexahedral mesh.

- Absorbing boundary zones with perfectly match layers (PML).

- Parallelized for multiprocessor execution with Message Passing Interface (MPI).

SC/EC
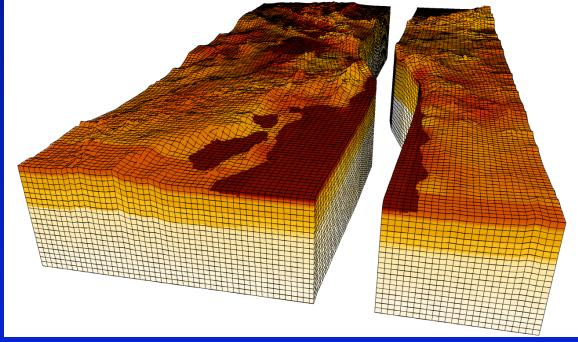
Uniform California Earthquake Rupture Forecast (UCERF)

CALIFORNIA FAULTS
Probability of M≥6.7 Earthquakes

1. S. San Andreas — 59%
2. Hayward-Rodgers Creek — 31%
3. San Jacinto — 31%
4. N. San Andreas — 21%
5. Elsinore — 11%
6. Calaveras — 7%
7. Garlock — 6%

Cascadia Subduction Zone

Sacramento

San Francisco

Los Angeles

San Diego

30-Year Earthquake Probability

- 100%
- 10%
- 1%
- 0.1%
- 0.01%
- 0.001%

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an NSF+USGS center

USGS
science for a changing world

CGS
CALIFORNIA GEOLOGICAL SURVEY

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M7.6 southern San Andreas scenario
SORD rupture dynamics simulation

0:00

Ground velocity magnitude

0.05   0.5   1 m/s

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M$_w$7.6 Southern San Andreas Simulation

- 600 x 300 x 80 km region, 200 m resolution: 1.8 billion elements.
- 200 x 16 km non-planar spontaneous rupture with stress drop inverted from the M7.3 1992 Landers strong motion records.
- Free surface topography and bathymetry.
- SCEC-CVM 4.0 velocity model.
- 0-0.25 Hz bandwidth.
- 3 min duration.

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Equations of Motion

Viscoelastic Solid (Kelvin-Voigt Model)

$$\ddot{\mathbf{u}} = \frac{1}{\rho}\boldsymbol{\nabla}\cdot\boldsymbol{\sigma}$$

$$\mathbf{g} = \boldsymbol{\nabla}(\mathbf{u} + \gamma\dot{\mathbf{u}})$$

$$\boldsymbol{\sigma} = \lambda\,\mathrm{trace}(\mathbf{g}) + \mu(\mathbf{g} + \mathbf{g}^{\mathrm{T}})$$

ρ	density
λ, μ	elastic moduli
γ	viscosity
$\mathbf{u}$	displacement
$\boldsymbol{\sigma}$	stress tensor

Free surface boundary condition

$$\boldsymbol{\tau} = \boldsymbol{\sigma}\cdot\hat{\mathbf{n}} = 0$$

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Spontaneous Rupture Boundary Condition

$$\mathbf{s} = \mathbf{u}^+ - \mathbf{u}^-$$

$$\boldsymbol{\tau}_n = \hat{\mathbf{n}} \cdot \boldsymbol{\sigma} \cdot \hat{\mathbf{n}}$$

$$\boldsymbol{\tau}_s = (\mathbf{I} - \hat{\mathbf{n}}\hat{\mathbf{n}}) \cdot \boldsymbol{\sigma} \cdot \hat{\mathbf{n}}$$

$$|\boldsymbol{\tau}_s| \leq \tau_c$$

$$\tau_c \dot{\mathbf{s}} = |\dot{\mathbf{s}}| \boldsymbol{\tau}_s$$
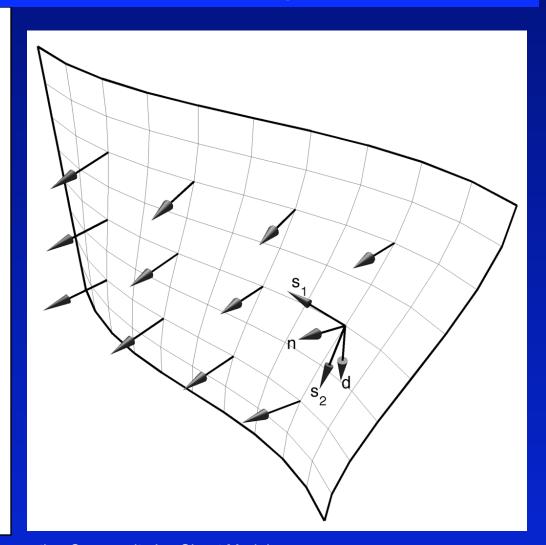
$\mathbf{s}$	slip
$\boldsymbol{\sigma}$	stress tensor
τ_n	normal traction
$\boldsymbol{\tau}_s$	shear traction
τ_c	frictional strength
$\hat{\mathbf{n}}$	surface unit normal

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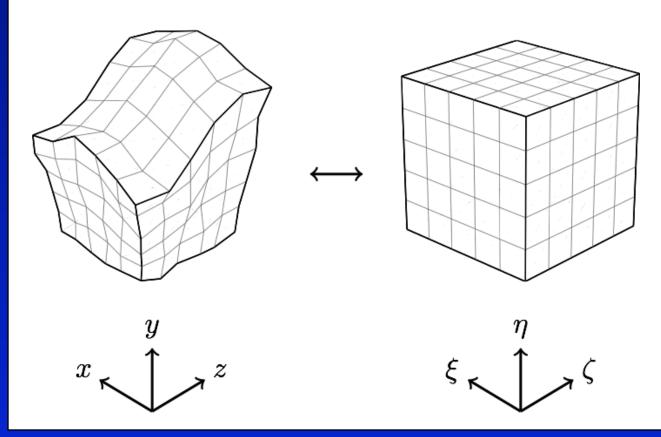
Support Operator Numerical Scheme

Derivation:

$$f(\boldsymbol{\xi}) = \sum_{\alpha,\beta,\gamma=0}^{n} N_{\alpha\beta\gamma}(\boldsymbol{\xi}) f_{\alpha\beta\gamma} \qquad \boldsymbol{\nabla} f = \frac{\partial f}{\partial \boldsymbol{\xi}} \cdot \mathbf{J}^{-1}$$

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Support Operator Numerical Scheme

Discrete gradient operator

$$(\mathbf{D}_i f)_{jkl} \approx \frac{1}{V_{jkl}} \int_{V_{jkl}} \partial_i f \, dV$$

Continuous divergence theorem

$$\int_V f(\boldsymbol{\nabla} \cdot \mathbf{w}) \, dV + \int_V \mathbf{w} \cdot (\boldsymbol{\nabla} f) \, dV = \int_S f\mathbf{w} \cdot d\mathbf{S} = 0$$

Discretized divergence theorem gives the negative adjoint divergence operator

$$\sum_{j,k,l=1}^{m,n,p} f_{jkl}(\mathcal{D}_i w_i)_{jkl} = - \sum_{j,k,l=1}^{m-1,n-1,p-1} (\mathbf{D}_i f)_{jkl}(w_i)_{jkl}$$

...and conservation of energy is obeyed.

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CMU Hercules platform
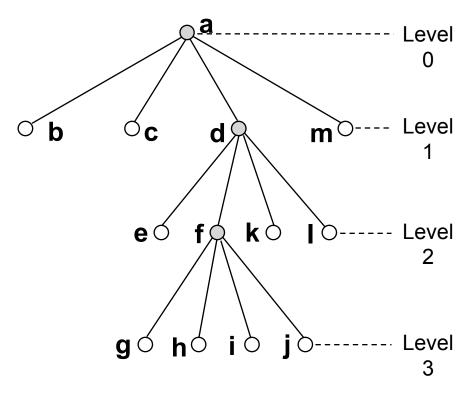
Finite element approach

Structured, variable mesh

Oct-tree management of model and simulations

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Equivalent Octree Representations

Domain Representation
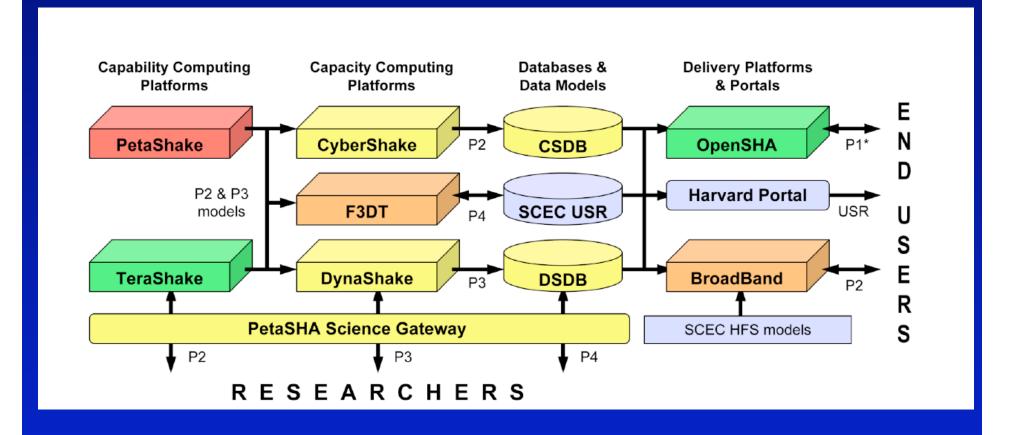
Tree Representation
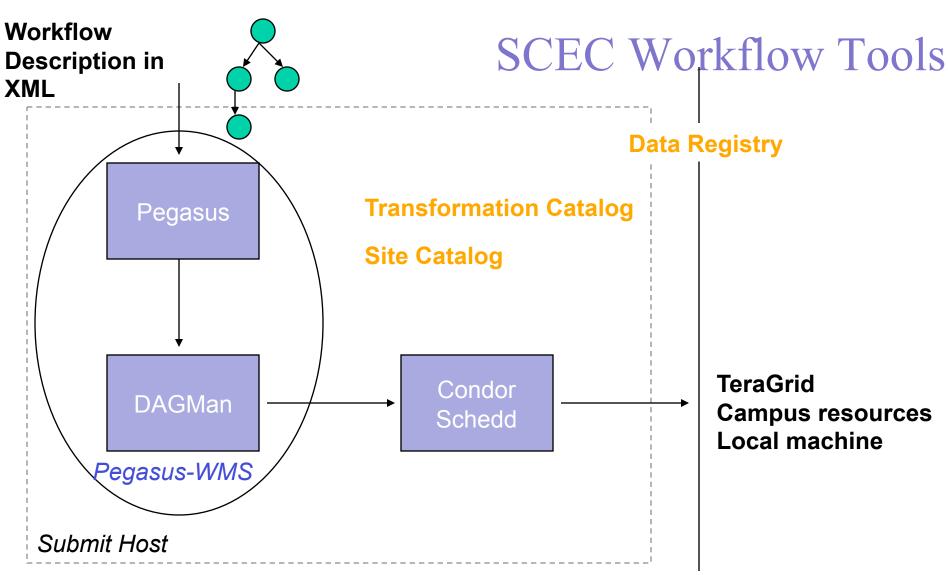
○ : Interior octant   ○ : Leaf octant

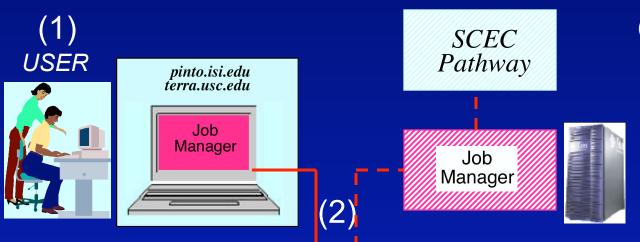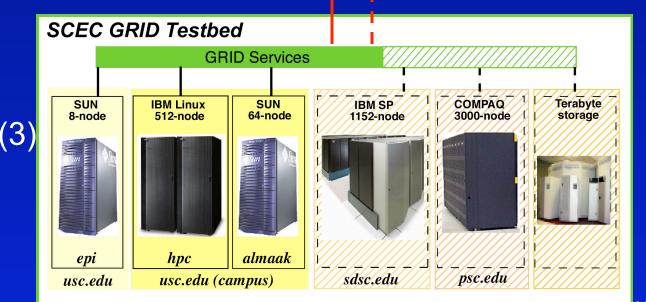Hercules System - David R. O'Hallaron

SCEC Computational Platforms

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SCEC Workflow Tools

Workflow Description in XML

Data Registry

Pegasus

Transformation Catalog

Site Catalog

DAGMan

Condor Schedd

Pegasus-WMS

Submit Host

**TeraGrid
Campus resources
Local machine**

Pegasus restructures and optimizes the workflow, provides reliability
Pegasus-WMS is a collaboration with UW Madison and funded by NSF under SDCI

SCEC Computational Grid Testbed

(1)
USER

pinto.isi.edu
terra.usc.edu

Job Manager

SCEC Pathway

Job Manager

(2)

SCEC GRID Testbed

GRID Services

| SUN 8-node | IBM Linux 512-node | SUN 64-node | IBM SP 1152-node | COMPAQ 3000-node | Terabyte storage |

epi   hpc   almaak

usc.edu   usc.edu (campus)   sdsc.edu   psc.edu

(3)

(1) *Scientist issues a request (compute or data retrieval) to "Job Manager"*

Future complex pathways require a more versatile Job Manager.
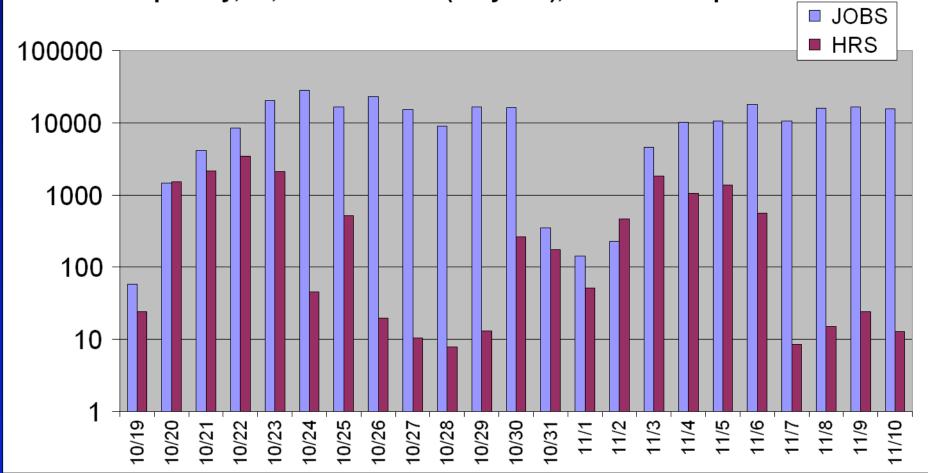
(2) *Job Manager talks to a Testbed computer via GRID service communication protocals.*

(3) *Testbed computer performs the requested actions.*

get Model

Were we were: Executions on the TG Fall 2005 (Pasadena and USC)

Number of jobs per day (23 days), 261,823 jobs total, Number of CPU hours per day, 15,706 hours total (1.8 years), 20TB of data processed

Managing Large-Scale Workflow Execution from Resource Provisioning to Provenance tracking: The CyberShake Example, Ewa Deelman, et al, e-Science 2006, Amsterdam, December 4-6, 2006, best paper award
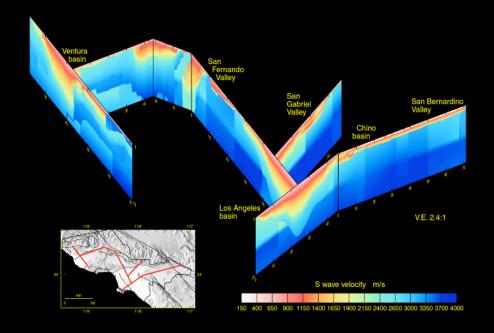
Code comparisons

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2002 SCEC Annual Meeting

PEER/SCEC Collaboration for Validation of 3D Wave Propagation Codes

Steven Day
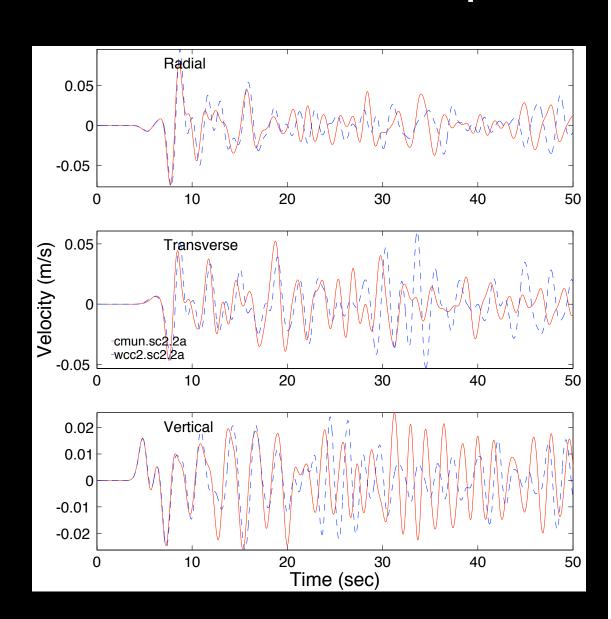San Diego State University

September 10, 2002

Stage II:
Complex Structure (perfectly elastic)

- **SCEC 3D Reference Model for So. California**
- **Modified for minimum S velocity of 500 m/s**
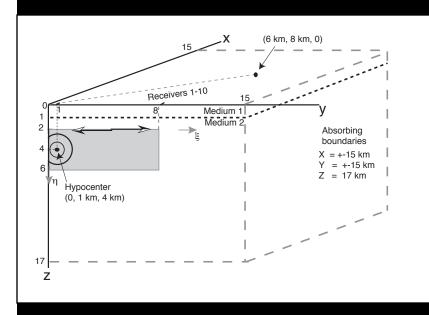- **Point dislocation source**
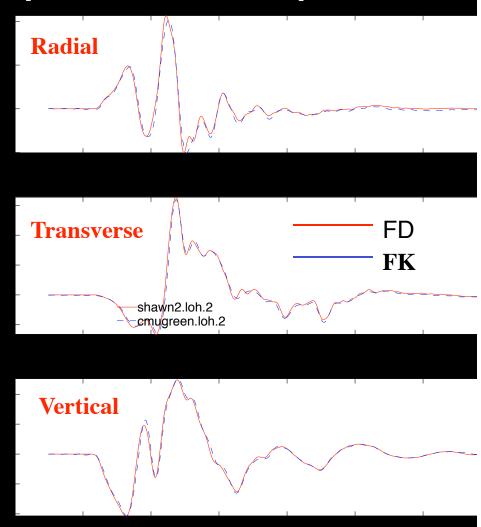- **Target bandwidth 0 - 0.5 Hz**

SCEC Reference Model Example

- Site in San Fernando Valley

- Point dislocation source in Northridge aftershock zone

- Very fine FE meshing of shallow sediments provides best reference solution (shown in red)

- Compared here with FD (blue)

Propagating Rupture Example

Low-velocity elastic layer

Propagating dislocation

Stage III

Anelastic Attenuation

No-memory methods (narrow absorption band)
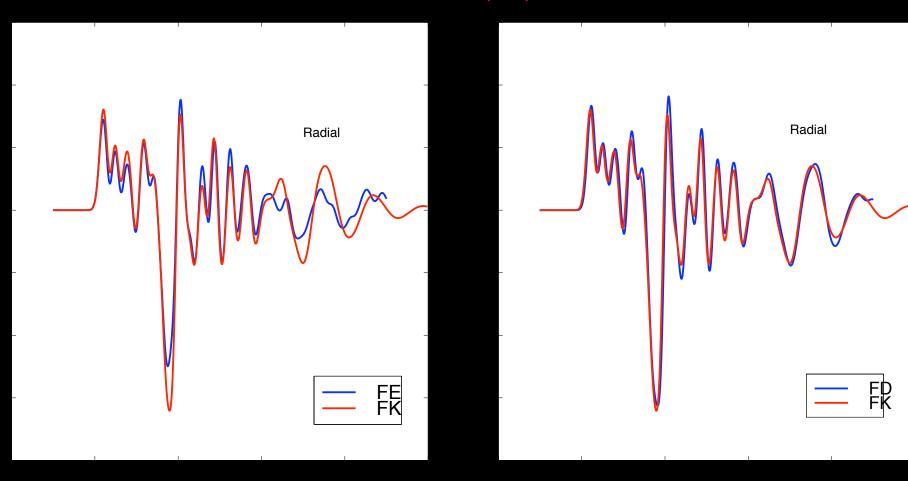
- Maxwell solid √
- Voigt Solid

Memory variable methods (broad absorption band)

- Conventional (anelastic relaxations on unit cell) √
- Coarse (anelastic relaxations on larger unit cell) √

No-memory-variable formulation (Maxwell)

Coarse memory-variable Formulation (8 relaxations)

Reference Solution (FK) in red

Radial

Radial

FE
FK

FD
FK

END

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